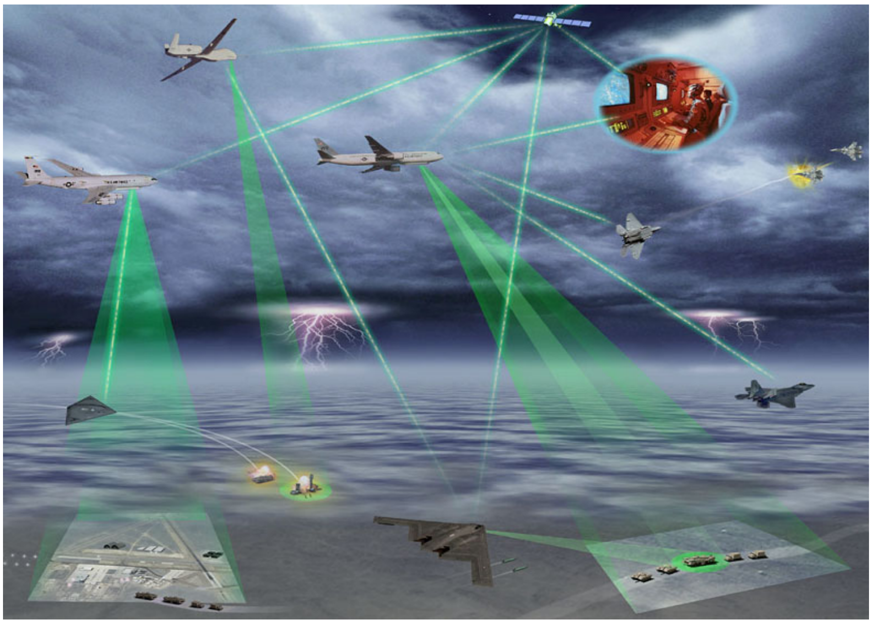
Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Collective Mission Simulation Capability for the Netherlands Armed Forces



Problem area
Due to a number of developments in the past decade, the relevance and importance of Collective Mission Simulation (CMS) has increased strongly. The Royal Netherlands Armed Forces have raised the ambition to establish a validated, reusable, and interoperable mission simulation environment that supports the distributed simulation of tactical and operational missions. To further extend their knowledge on the subject of CMS and support developments of new processes, methods and technologies a research program on "Collective Mission Simulation" was started.

The first main problem area concerns issues of *effectiveness* in CMS environments. The difficulty in this area is to develop a CMS environment that is fit for purpose on one hand and reusable and interoperable for another purpose. The main question we want to answer here is: what is needed for creating *effective realism* in a CMS environment?

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This report is based on a presentation held at the I/ITSEC, Orlando (FL), USA, 1 December 2010. The paper received an honorable mention for best paper award.

The second problem area is *systems interoperability*. The difficulty in this area lies in the currently used simulators, which were never designed to cooperate in a CMS environment and therefore may have only limited possibilities to do so. Important questions in the area of CMS to answer here are:

- What *interactions* are needed and are possible between simulators?
- How can we ensure a *level playing field*, i.e. creating fair fight-fair play?
- How can we foster *reuse* of reference data, models and simulation components?

The third problem area is the *management of the mission information flow*. When setting up a CMS environment in a joint context, one is confronted with many different architectures, tools, and procedures which logically enlarge the interoperability problems, and ask for effective mission information distribution amongst participants and supporting staffs. The main research question in this area is: *how to ensure a seamless information flow across dispersed locations addressing effectively various user needs*?

Description of work

The Dutch CMS research program was built around a number of practical use cases. Several technology demonstrators and experiments were held to test and evaluate various, mostly technical, solutions for collective mission simulation environments.

In the first problem area we have investigated a unified model driven method to create systems engineering models that merges distributed simulation specific standards with standards and best practices from the domains of systems and software engineering. This development process is combined with a goal based derivation of the intended purpose to the level of concrete and testable acceptability criteria for determining how useful the developed simulation environment for the user will be.

In the second area a number of supporting tools and methods are developed and tested for specifying interactions in a CMS environment, reusing simulation components and models and ensuring a level playing field.

In the third area we investigated different types of tools and various working methods to develop a framework and CONOPS for a distributed debriefing set-up.

Results and conclusions

The CMS program was built around a number of practical use cases and based on a research by doing approach. Several technology demonstrations and experiments were held to evaluate solutions for CMS environments from multiple angles, e.g. technically, organizationally and operationally. Feasible and novel solutions for CMS have been created and due to the research by doing approach researchers and military operators have gained actual experience with working in a CMS environment.

Applicability

In our CMS research we developed and tested an approach, methods and technologies that address a number of shortcomings with respect to successfully implementing a CMS environment that supports collective missions in combined and joint settings. This enables the Dutch Armed Forces to start building a national CMS capability. This capability has now been named Orange WAVE (Warfighter Alliance in a Virtual Environment). Orange WAVE will support the national needs as well as facilitate future Dutch participation in Live, Virtual and Constructive (LVC) coalition training events.

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Collective Mission Simulation Capability for the Netherlands Armed Forces

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Summary

Military forces all over the world are transforming to adapt to the changed world politics. The application of the latest technology is key in this transformation process. Examples of operational changes are more expeditionary operations, joint and combined operations, information data management, and distribution of information. An important area where technology plays a key role in the ongoing transformations is mission training and rehearsal. Developments in modeling and simulation allow Collective Mission Simulation (CMS) in combined and joint settings in a synthetic environment. The Royal Netherlands Armed Forces have explored CMS through participation in a number of virtual exercises. The potential of collective mission simulation has been recognized and the requirement for a CMS capability was formalized. The Royal Netherlands Armed Forces want to establish a validated, reusable, interoperable mission simulation environment that will support the distributed simulation of tactical and operational missions at varying levels of security classification.

The requirement for this capability initiated the start in 2006 of a 4-year national research program into collective mission simulation (CMS), which focused on effective realism, interoperable systems across domains and management of the mission information flow. In this paper we will describe the main results of our research and address the Dutch vision on enhancing mission training and mission readiness with a national CMS capability. This capability has now been named Orange WAVE (Warfighter Alliance in a Virtual Environment). Orange WAVE will support the national needs as well as facilitate future Dutch participation in live, virtual and constructive coalition training events.

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Contents

Abbreviations

CGF	Computer Generated Forces
CMS	Collective Mission Simulation
CONOPS	Concept of Operations
CTF	Common Technical Framework
DDCP	Distributed Debriefing Control Protocol
DMO	Distibuted Mission Operations
EDA	European Defence Agency
GIS	Geographic Information System
GMVV	Generic Methodology for Verification and Validation
HLA	High Level Architecture
JE^2C^2	Joint Exercise & Experimentation Coordination Centre
JPOW	Joint Project Optic Windmill
JPT	Joint Planning Tool
LVC	Live Virtual Constructive
MDA	Model Driven Architecture
MD3S	Model Driven Development for Distributed Simulation
MOUT	Military Operation in Urban Terrain
M&S	Modeling & Simulation
MSG	Modeling and Simulation Group
MTDS	Mission Training through Distributed Simulation
NATO	North Atlantic Treaty Organisation
OMT	Object Model Template
PDG	Product Development Group
R&D	Research & Development
RTO	Research & Technology Organisation
SISO	Simulation Interoperability Standards Organization
TACTIS	Tactical Indoor Simulator
TRM	Threat Reference Manual
ULT	Unit Level Trainer
UML	Unified Modeling Language
WAVE	Warfighter Alliance in a Virtual Environment

1 Introduction

Mission training and rehearsal are vital to successful operations. Simulation has been a versatile tool for these purposes. In the beginning of this millennium mission training via distributed simulation was the topic of the day in the military training world. Several technology demonstrators were developed and demonstrated the technical possibilities of connecting distributed simulation environments. An example of such demonstration in the Netherlands was the project ULT-JOIND [Janssen, 2002], where a successful connection between distributed air and ground simulations was realized.

Figure 1. The ULT-JOIND network, a national CMS demonstration that involved air and ground simulation assets

The value of mission simulation has been demonstrated in application areas such as operational analysis, system acquisition, training and mission rehearsal. Mission simulation differentiates itself from platform simulation in that mission simulation involves tactical or operational aspects of a military mission. When involving multiple, potentially geographically dispersed simulators, we talk about Collective Mission Simulation (CMS). In CMS, interactions between the simulated entities and between these entities and their simulated environment (both tactical and natural) are of prime importance.

To date, the Royal Netherlands Armed Forces have exploited collective mission simulation on a case by case approach, as for example in the live-virtual, and constructive (LVC) exercise series Joint Project Optic Windmill (JPOW) [Jacobs et al, 2009]. Due to its successful participation [Gehr et al, 2005], in NATO's first Mission Training through Distributed Simulation (MTDS) event First WAVE [NATO RTO task group SAS-034/MSG-001, 2007], The Royal Netherlands Armed Forces have raised the ambition to establish a validated, reusable, and interoperable mission simulation environment that supports the distributed simulation of tactical and operational missions at varying degrees of security classifications. To further extend their knowledge on the subject of CMS and support developments of new processes, methods and technologies a 4-year national research program on "Collective Mission Simulation" was started in 2006. Also, a national M&S policy has been developed to create an integral vision to acquire and exploit M&S capabilities, including CMS.

In this paper, we will present an overview of the results of our national CMS research program. The results will be outlined along three main subjects: effective realism, interoperable systems across domains, and management of the mission information flow. We will conclude this paper with the Dutch vision on enhancing mission training and mission readiness with a national CMS capability, named Orange WAVE (Warfighter Alliance in a Virtual Environment).

2 The need for Collective Mission Simulation

Due to a number of developments in the past decade, the relevance and importance of CMS has increased strongly. Some of these developments are:

- Growing number of out-of-area operations, often with short preparation times;
- Frequently changing missions in complex (urban) environments, e.g. joint and combined, multinational coalitions (e.g. Iraq, Afghanistan);
- Increasing peace-time limitations for live mission training and rehearsal, due to e.g. budget and system life time limitations, environmental constraints, security and safety issues;
- Decreasing availability of operational systems for mission training and rehearsal (due to more and longer operational deployments);
- Rapidly increasing simulation capabilities within the Royal Netherlands Armed Forces, such as the introduction of the Tactical Indoor Simulator (TACTIS) for collective maneuver training

All of these developments have led to a growing need for a collective mission simulation environment that can support concept development and experimentation, e.g. in the areas of system acquisition, tactics and doctrine development, and command and control, as well as mission training and rehearsal. CMS addresses these challenges by providing the military with a distributed simulation environment that allows units to participate from their own base in distributed mission training events, In simulation it is rapidly getting easier to provide the military with a mission rehearsal environment that is fit for purpose, realistic and can be used over and over in time for both individual, team and collective mission preparation.

3 Overview of the CMS research program

The Dutch CMS research program was built around a number of practical use cases. Several technology demonstrators and experiments were held to test and evaluate various, mostly technical, solutions for collective mission simulation environments. This *research by doing* approach was taken deliberately to ensure that the full complexity of creating feasible and novel solutions for CMS could be investigated and exploited from multiple angles, e.g. technically, organizationally and operationally. The additional benefit was that this approach gave researchers and military operators, the opportunity to experiment with and gain actual experience with working in a CMS environment.

Also a strong cooperation with international (research) efforts and programs on distributed simulation from coalition partners, such as the UK Mission Training through Distributed Simulation (MTDS), the US Distributed Mission Operations (DMO), and NATO Snow LEOPARD [Löfstrand et al, 2009] [Cayirci et al, 2009] programs, were sought to ensure that our national developments were concurrent with international developments. Examples of these cooperation initiatives were the NATO Live Virtual Constructive (LVC) Architecture [NATO RTO Task group MSG-068, 2007], SISO's Generic Methodology on Verification and Validation (GM-VV) [SISO GM-VV PDG 2010], NATO Missionland [Lemmers et al, 2009] [Lemmers et al, 2010], and the European Defence Agency's (EDA) Core Framework [Tegnér et al, 2009] [Suzic et al, 2009].

Our national CMS research has also led towards the start of novel international research programs, such as MSG-080 [NATO RTO Task group MSG-080, 2010], which will guide further the research on finding solutions to address and overcome security challenges when creating a CMS environment that needs to take into account various classification levels of simulators and operations in a single event.

4 Overview of the CMS research results

In the sections below the main results of the CMS program are described. We organized the R&D in the program around three main areas.

The first main problem area concerns issues of *effectiveness* in CMS environments that will be used for multiple purposes, such as Concept Development & Experimentation (CD&E) for material procurement, Command & Control (C2) support, and Tactics & Doctrine development, as well as mission training and rehearsal. For all these applications, we have to deal with utility, validity and correctness of such an environment. The difficulty in this area is to develop a CMS environment that is fit for purpose on one hand and reusable and interoperable for another purpose. If it is not fit for purpose, effectiveness problems will show up, or even worse negative transfer of training or experimentation results may occur. However, just asking for the best possible fidelity is not the solution. The main question we want to answer here is: *what is needed for creating effective realism in a CMS environment?*

The second problem area is *systems interoperability*. The difficulty in this area lies in the currently used simulators, which were never designed to cooperate in a CMS environment and therefore may have only limited possibilities to do so. Current (legacy) simulators, and probably also some of the future simulators, are systems that are closed black boxes. They often do not provide good means for interoperability and reuse. Important questions in the area of CMS to answer here are:

- What *interactions* are needed and are possible between simulators?
- How can we ensure a *level playing field*, i.e. creating fair fight-fair play?
- How can we foster *reuse* of reference data, models and simulation components?

The third problem area is the *management of the mission information flow*. When setting up a CMS environment in a joint context, one is confronted with many different architectures, tools (and associated security regulations), and procedures which logically enlarge the interoperability problems, and ask for effective mission information distribution amongst participants and supporting staffs. When executing a joint, multi-level, coalition training event one problem is to maintain consistency in the information that is provided to the users at the different levels and locations, throughout the entire mission - from mission planning, briefing, execution, analysis to debriefing. The main research question in this area is: *how to ensure a seamless information flow across dispersed locations addressing effectively various user needs?*

4.1 Effective Realism

How to build a CMS environment that is effective with respect to the set objectives? Faced with already existing simulators, optimal matching of these simulators in creating an appropriate mission simulation environment is complex. Often however these simulators can be connected together and configured such that they have at least basic interactions in a common environment. But that is usually a costly process, both in terms of time and money required, and determining whether such simulation systems are valid for these intended uses is very difficult.

In our research we have investigated a unified model driven method to create systems engineering models that merges distributed simulation specific standards with standards and best practices from the domains of systems and software engineering. Currently, there is no general agreement on one method to produce engineering models for distributed simulations that covers the complete development process. Rather, the various stages of development are supported by dedicated methods and resulting engineering models. The work that is most closely related to the presented vision is that on conceptual modelling, especially those that adopt formal modelling languages such as the Unified Modelling Language (UML) as basis for conceptual modelling [Tolk, 2003].

The method we propose in our research, called Model Driven Development for Distributed Simulation (MD3S), is used to produce a unified engineering model. MD3S takes the use of UML for conceptual modelling a step further by combining it with the concepts of the Model Driven Architecture (MDA) to cover all steps of the development process up to and including implementation. This combination offers a number of advantages when trying to optimize the effectiveness of CMS environment. Firstly, the user requirements remain clearly traceable during the different stages of specification and development. Also all aspects required for full interoperability are taken into account. The fact that MD3S uses a more formal specification makes it also less susceptible to misinterpretation [Keuning et al, 2008].

MD3S covers one side of developing an effective mission simulation environment. The other side of the development process (see Figure 2) is determining how useful the developed simulation environment for the user will be.

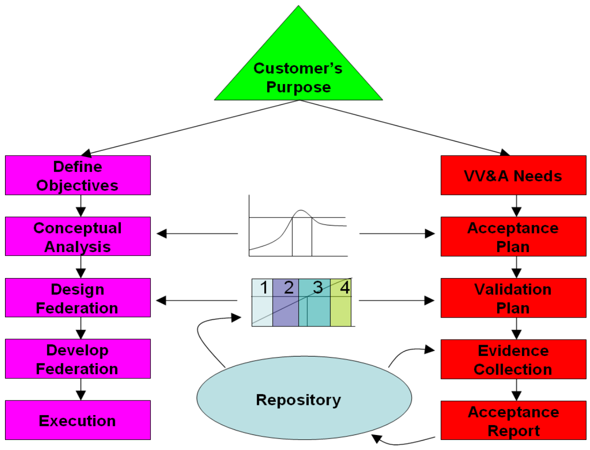

Figure 2. CMS Development process

When confronting users with questions on what fidelity is needed for their uses, the answer often is something like "it must be as close as possible to the real world". This, however, is in general either practically impossible or very costly.

Besides the limitation on simulating reality and costs there is a number of other elements that put limits on how useful the simulation system will be to the user. To start, there is the factor of time. This includes not only simulation development time but also the time needed to prepare the federation for a specific execution. The available expertise of supporting personnel can be a significant limit on final usability. Often a new federation is built by reusing many already existing components. This saves budget but hinders the possibility to tailor the new simulation system to its intended use. Depending on the situation many more limitations may be present.

Dealing with all these limitations causes developments to strive towards the effective use of simulation means in CMS. For the effective use of CMS it is important that the simulation systems adequately represent the relevant parts of reality. But reality is not the only thing that must be effective. The simulation system must also be built correctly according to specifications and be free of impeding faults. Moreover, it must be demonstrated that the simulation system fulfils the users' needs, does not pose any unacceptable risks or exceeds the budget.

Clearly, asking for the best possible fidelity is not the solution for effective use of simulation means. For all options in constructing and using an M&S system it must be clear what the impact is on the intended purpose and the risk involved.

The proposed solution is to make a goal based derivation of the intended purpose to the level of concrete and testable Acceptability Criteria. The derivation and formulation of these criteria must be made with effectiveness in mind, e.g. what is the impact on the intended use if the system crashes once a day if it can be restarted in 5 minutes? Available options for the construction and use of a CMS environment can be matched with the acceptability criteria to see if any fail. If so, either a different option must be chosen, the current option must be adapted (which costs resources), or the intended purpose can be limited such that the criterion is no longer failed. For an optimal decision it is necessary to weight all possible options with their impact on the intended use and their resource (time, budget, skills, etc.) usage. At several places during the development or configuration of a CMS environment choices must be made to reach overall effectiveness. [Voogd et al, 2009].

An example of how an effective and realistic solution was determined during construction of one of the test cases in the CMS research program was the calculation of damage resulting from a bomb dropped from a fighter plane. Several implementation options were available, ranging from symbolic, e.g. a fixed size black circle in the terrain, to a computation intensive model that takes many variables into account. After discussions with the customer's subject matter experts it was decided that the symbolic version was not good enough and that the top range version resulted in overkill. The model that was chosen was a 2D table with damage results calculated by the top model for typical values of the two most important variables of a falling bomb (speed and angle). During the simulation execution damage was calculated by interpolation of values in the table. Later, off-line, the simulation data for the falling bomb was used in the full computational intensive model to check that the deviation with the interpolated data was sufficiently small.

4.2 Interoperable Simulation Systems

When more simulators are to be joined, one of the important questions is: *what interactions need to be specified and ensured between participating simulations?*

Specifying interactions in a CMS environment

For identifying the possible interactions between entities participating in a CMS environment we have developed a query tool that supports the design of a CMS event through analyzing available information in Threat Reference Manuals (TRMs) and then generates a report with all possible interactions between entities. The benefit of a database containing all relevant systems and their frequencies is in the limitless number of entities and effective and thorough search of all possible interactions. For two or three entities this can still be done by humans with some expertise about the technologies, but with more complicated scenarios the benefit of a computer-based interaction tool becomes clear. During our research, this tool has been extended with a number of filters that give the user the possibility to select what aspects and entities have to be taken into account. The use of these filters results in a relevant and realistic list of (needed) interactions.

Next to creating systems overviews, a start has been made with implementing also atmospheric interactions into the database and query tool, enhancing the interaction analysis from system to system to systems and their environment.

Using multiple types of models and simulations in CMS

When the required interactions are defined a start can be made with defining and selecting the models and simulations that are needed for the CMS environment. For collective mission simulations a common model and parameter set is preferable. Otherwise, a cooperation or confrontation between the occupants of these simulations has possibly reduced value, since performance of systems is different in the two simulations. The concept of connecting two simulators also can put restrictions on the classification that data transferred over the connection line can have, or one of the simulators can be used in a location that forbids data of a certain classification to be used.

In some simulations, the full range of high fidelity calculations is required to be able to test new technology concepts or tactics, while in many cases a more black box approach will suffice, for instance just taking into account range and time of impact. Therefore in our research we implemented both physics based models as well as capability based models with the objective to extend knowledge on:

- How to develop models, which are suitable for use across simulations?
- How to make good use of existing information databases?
- How to select the most effective, performance and cost wise, model for an objective?

Reusing simulation components in a CMS environment

The idea of reusing simulation components when developing simulations is appealing because it could save both time and money. In practice, however, it can be difficult to reuse a simulation component for other purposes than for which it was originally developed. In particular, reusing simulation components across application domains, or multifunctional reuse, can be challenging. It would be valuable if we had more insight into the conditions that determine the suitability of a simulation component for multifunctional reuse. In this context, we investigated the terms and conditions for multifunctional reuse of simulation components across different domains, in particular the reuse between the domains of training and materiel (concept)

development. Our conclusions are in line with current Component Based Development and Service Oriented Architecture principle: reuse is facilitated by applying componentization and ensuring that components have well-defined interfaces. Additionally, we have defined the main subjects for guidelines for the development and application of multifunctional components. These consider constructive as well as virtual simulations and include aspects of time management, model configurability, componentization, and interoperability.
[De Kraker et al, 2007]

How to create a level playing field in CMS?
Next to finding solutions for specifying and designing an appropriate CMS environment we have also investigated solutions that enhance the effectiveness of CMS during the execution of events. A major challenge is how to ensure fair-fight and fair-play between existing simulators that have been designed for varying purposes and come together in a CMS environment.

Remember those days of playing “Cowboys and Indians”? Then you probably also remember having an argument over the outcome of a shooting incident. Some kid would shout: “You’re dead!”, while the assumed victim would firmly acclaim: “No I’m not, you’ve missed me!” The same argument still happens today in distributed simulations, where individual simulators draw conflicting conclusions on the result of weapon engagements or the capabilities of sensors. While one simulator assumes that an entity has been killed, another simulator still has that same entity alive and kicking. This occurs especially with legacy simulators that do their kill assessment internally. To resolve this issue and to achieve a level playing field, each simulator should adhere to the simulation agreements and should preferably use identical implementations. Although it is unlikely that all actual details of weapons, sensor systems, etc. will ever become available for reasons of security, commercial or national interest, it is important that an improved and, as a minimum, consistent behavior of these CMS systems is achieved.

A level playing field, i.e. consistent behavior of all systems/models across the CMS environment, should be ensured. We investigated the concept of independent handlers that enforce their conclusions upon joined simulation systems, since this will allow for simulator independent solutions. The concept of using independent handlers, with an interaction server, is not restricted to kill assessment, but can also handle the behavior of weapon systems and countermeasure systems. The handlers provide a means to show how to manage security sensitive agreements such as weapon behavior and countermeasures. In this way it helps to achieve a level playing field for all participants in one federation.

We developed a prototype that showed how to handle effectively such interactions between entities and entities, and between entities and their environment, and even multiple interactions e.g. between entities and aggregates [Boomgaardt et al. 2007]. Figure 3 shows an overview of the interaction handler architecture.

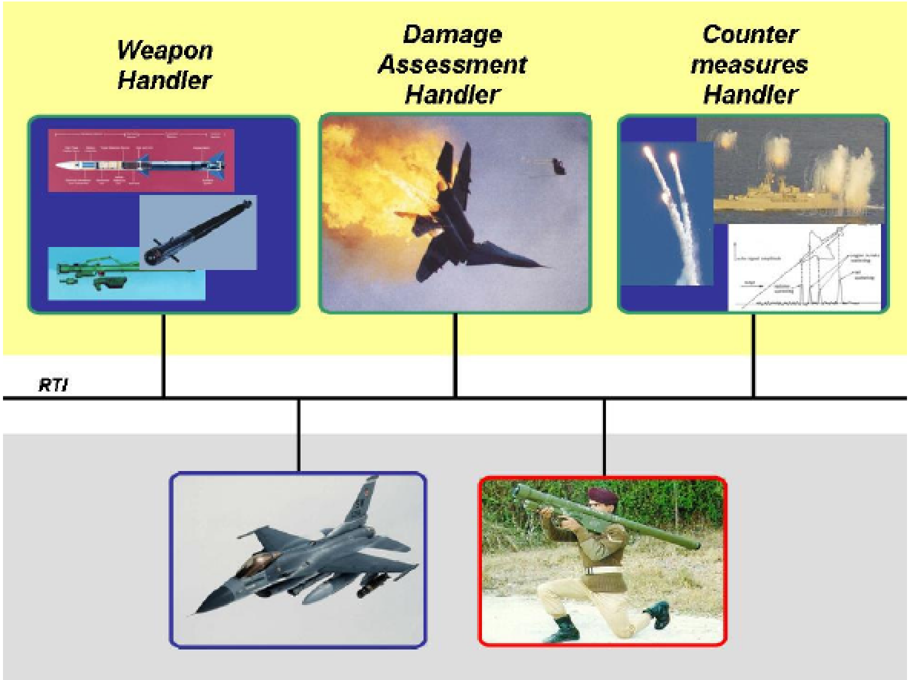

Figure 3. Interaction Handler Architecture

How to create a collective mission environment?
The effectiveness of simulation applications for training and mission rehearsal is greatly influenced by the availability of high quality terrain databases. The creation of these databases is typically performed in three possible ways:

- The terrain is automatically built using terrain generation software. The input data consists of externally acquired Geographic Information System (GIS) data that is readily available: elevation data, imagery and vector data.
- The terrain is automatically built using terrain generation software, but only elevation data and imagery are acquired externally from readily available sources. The vector data describing the features in the terrain is generated by manual editing using the imagery as input.
- The terrain is fully manually modeled using an interactive 3D modeling tool. This method is often applied for small terrains, with a high level of detail. Either real world maps/images or imaginary maps/sketches are used as input.

The latter two methods will normally generate detailed results, but at the cost of significant manual labor. The first method is more attractive in terms of the amount of manual editing that is required. However, three main problems arise when working from readily available GIS data:

- When the GIS data is acquired from various sources, correlation errors are likely to occur.
- For remote locations, these data sources will be either not available or of poor quality. The data will typically not allow for accurate 3D modeling of features.

To overcome these problems while still minimizing the amount of manual editing, automatic techniques are needed to extract the required GIS data from sensor data sources.

Building terrain databases automatically from geo-specific source data can be very efficient but, in some cases, does not deliver the most effective database for the purpose of the simulation. For mission rehearsal and training exercises with live components involved, the use of geo-specific source data is mandatory since the terrain database should accurately resemble the real mission area for these cases. Often, the same type of geo-specific database is also used for more basic training purposes. Given a specific training task, the geo-specific terrain is searched for a location that is suitable for a scenario serving this particular training task. This can be a valid approach, since building a terrain database from geo-specific data can be cheaper than fully manually modeling a terrain that fits the purpose. However, if better automatic techniques were available that create an imaginary terrain that fits the training purpose, this would result in more effective terrain databases at lower cost. With SketchaWorld, a concept that creates detailed terrain databases using procedural techniques based on sketch user input we developed solutions in this area [Kuijper et al, 2010].

Lessons learned on the subject of creating terrain databases for CMS demonstrate that techniques and tools and even standards are readily available to support collective mission simulation. Although standards for correlated exchange of complete terrain models are available, current best practice is still to exchange at the level of source data while accurately prescribing the rules for terrain generation to minimize correlation problems.

In support of various case studies in our CMS research two (collective) terrain databases were developed: the *Marnehuizen* database, representing a Military Operations in Urban Terrain (MOUT) training village in The Netherlands, and an *Uruzgan* database (see Figure 4), representing the current Dutch mission area in Afghanistan.

Figure 4. The Uruzgan database. A geospecific model the Afghan mission area, modeled on the basis of satellite imagery.

Terrain databases can be of great influence on effectiveness when terrain correlation between systems is not well controlled. For the Marnehuizen database, this was no issue in our setup: all systems derived their data directly from a fully computed OpenFlight terrain representation. The Computer Generated Forces (CGF) system (VR Forces by MäK Technologies) also derived height data from the OpenFlight visual terrain representation, while vector data for routing and collision detection was derived from correlated vector data.

The cases that used the Uruzgan database clearly showed the pain of terrain correlation. Having to cope with simulator-specific restrictions, this database could not simply be distributed at the fully computed OpenFlight level. As commonly applied, this database was distributed at the source level and computed separately for each of the visual systems. Even when computed with the same database generation system, this inevitably leads to correlation errors, exposed through vehicle that float above or dig into the terrain. These problems can only be overcome by strictly defining the terrain skin generation rules and limiting the complexity to the limits of the weakest system, apart from the usual work around to clamp vehicles to the terrain as known in the specific visualizing simulator.

How to create a coherent atmosphere in CMS?
The effects of atmospheric conditions on mission success are numerous, and are always of high importance during mission planning and execution. The main research question we have raised in this area was: *Which information concerning the environment is relevant and how can this information be integrated coherently in a CMS environment?*

The properties of the atmosphere can be described by its composition and condition. The composition specifies the quantity of the different gasses that are present in the atmosphere. The quantity of a certain gas present at a certain location and time in the atmosphere can have significant influence on the atmospheric interactions. Besides the composition, also the condition of the atmosphere at a certain location is relevant. The condition refers to values like the temperature, density, pressure or humidity and how those properties vary with location and time. Another aspect of the physics taking place in the atmosphere is how electromagnetic radiation travelling through the atmosphere interacts with it. This interaction is determined by the refraction, reflection, scattering and absorption processes taking place in the atmosphere.

Although the physical background of the atmosphere allows describing the interactions taking place, it is necessary to classify them in usable categories to be able to retrieve them efficiently. A first step in this process is to translate common atmospheric phenomena to the physical information model. This relates phenomena like wind, clouds, rain or smoke to the elements like pressure, density or atmospheric composition. Combining this with the electromagnetic radiation interactions gives insight on how those phenomena affect such radiation. A second step is to categorize entities and their sensors, so that more general conclusions can be drawn about which entity type or sensor type is affected by which kind of atmospheric phenomena.

An information model has been constructed for atmospheric interactions. This information model allows easy linking between atmospheric phenomena and the related parameters that are of importance within the (distributed) simulation, and vice versa. Figure 5 gives a graphical representation of the information model and the relations defined in it.

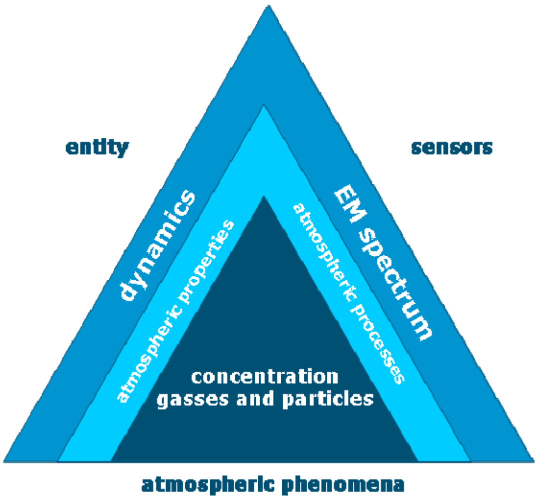

Figure 5. Atmospheric Information Model

The information model can be used to determine which information should be shared within a distributed simulation to effectively depict certain atmospheric interactions, but also to evaluate the influence of withholding certain information from the other participants. The information model can also provide information on the parameters that need to be taken into account when modeling a certain atmospheric phenomenon, and its influence on the entities and sensors, in the simulation.

4.3 Management of Mission Information Flow

When executing a joint, multi-level, coalition training event it is challenging to deliver relevant mission information in an appropriate and timely manner to various types of users at different levels and locations, throughout the entire mission - from mission planning, briefing, execution, analysis to debriefing. The main research question in this area was: *how to ensure a seamless information flow across dispersed locations addressing effectively various user needs?*

Experimenting with tooling and organization

Next to creating an environment that enables and supports the distributed information sharing and cooperation amongst participants during each stage of a mission a challenge is to determine how 'joined' solutions should be and how to develop an effective *concept of operations (CONOPS)* for conducting distributed mission planning, briefings and debriefings.

In our research we investigated different types of tools and various working methods to develop a framework and CONOPS, enabling a seamless information flow, for the Dutch national CMS environment. With respect to tooling we developed a framework for sharing appropriate mission data across multiple sites and supporting different types of users during the entire mission: e.g. providing the exercise/experiment control cell with appropriate logging, analysis and control mechanisms, and operators with (joint) planning and debriefing solutions. As we envisaged the need for mission-specific and user-centric solutions and a common framework at the same time we experimented simultaneously with developing a joint framework, integrating operational tools in use with the Royal Netherlands Armed Forces, experimental tools, and international initiatives in this area such as the Distributed Debriefing Control Protocol [SISO DDCP Study Group, 2009]

Based on previous research on innovative debriefing solutions [Jacobs et al, 2006] and [van Son et al, 2008] we have created a test environment for distributed planning, briefing and debriefing. Within this environment, a data flow passes all stages of a mission and is used to supply the user with the information needed at every stage. We investigated various tools and solutions that can support this information flow, and experimented with the feasibility of the DDCP protocol. The DDCP protocol is used to control and synchronize playback of mission data and multimedia content among training devices across a long-haul network during Mass Distributed Debrief operations. The DDCP approach provides distributed synchronization without the requirement to replay data across the distributed network, or through use of common tools. Such capability enables operators to use the same tools with which they are already familiar [Armstrong 2007] [Pitz et al 2007].

Based upon the results of the experiments we have developed a CONOPS for distributed mission planning, briefing and debriefing, next to giving practical guidelines for providing exercise support, also ensuring a smooth information flow for mission/exercise/experiment support personnel. We have captured this, together with other practical lessons learned from our research in a digital (Wikipedia) CMS Handbook.

Our research in this area will continue, partly within other research programs and also by using, testing and developing our solutions further in joint, distributed, LVC events such as, for example, in JPOW 2010. In this exercise a joint planning tool (JPT) [Wassenaar, 2010] and a prototype of a joint analysis tool suite (JOINT) [Kerbusch et al, 2010] is used.

How to overcome security challenges that arise in coalition events and simulations with different levels of security? Often the simulation models used in CMS environments exist within different security domains and these models need to be protected while information needs to be shared between the different simulators. Therefore, there is an increasing need for a multi level security solution that enables the sharing of simulation information across these security domains to establish collective simulations. In a CMS environment simulation systems are interconnected to each other and work together to reach a common objective. For example, the creation of a new airplane requires different commercial companies to interconnect their simulation systems and test the overall performance of the airplane. The simulator systems can have their own characteristics and information with possible conflicting interest of the organizations and security risks that are involved. These conflicting interests, or risks, could result in the limitation of information that is shared between the systems. Therefore, we have developed a concept that could be applied to prevent leakage of sensitive information. This concept is translated to the High Level Architecture (HLA) and a more detailed description is given of the different security mechanisms “security labeling” and “information release”. The Object Model Template (OMT) of HLA is used as the starting point for this security solution. We have developed a successful prototype demonstrating the feasibility of our concept [Verkoelen et al, 2009].

To further the implementation of this concept and enhance international cooperation on the subject of Multi Level Security an international NMSG working group was started in 2010 to continue research in this area [NATO RTO Task group MSG-080 2010].

5 Towards an integrated CMS capability

The current facilities in the Royal Netherlands Armed Forces show a number of shortcomings with respect to successfully implementing a CMS environment: [Voogd et al, 2008]:

- The organization is not optimally structured for developing, and using a CMS environment and policies are lacking for gaining the most out of the current facilities,
- Methods and procedures need to be adapted or new ones constructed for operating an CMS environment,
- Facilities need to be tailored for (distributed) CMS by offering specific services, and being flexible, reusable and future proof,
- Effectiveness and fit-for-purpose need to be defined for the different applications,
- System interoperability can be expected to be a problem when systems built for such diverse backgrounds are connected on a large scale,
- Security issues need to be tackled in an effective way before users are allowed and willing to use a CMS environment.

In our CMS research we developed and tested an approach that addresses these shortcomings and that is aimed at obtaining a CMS environment that supports collective missions in combined and joint settings. This approach transforms current ad hoc practices into a new paradigm that effectively and efficiently supports the delivery of the combat readiness of the Dutch Armed Forces. The approach, methods and technologies have been captured in our CMS handbook. To realize this approach, a number of enabling building blocks need to be instantiated. The identified building blocks are:

- The current organizational structure needs to be changed in order to develop and maintain a CMS environment,
- Handbooks need to be present on various levels of the CMS organization to coherently acquire, build, operate and maintain the CMS environment,
- A Common Technical Framework (CTF) is necessary to connect the necessary elements in a secure and meaningful way,
- A set of centralized services with their distributed counterparts are needed for smooth operations and a level playing field.

It is the ambition of the Royal Netherlands Armed Forces to enhance mission readiness with a national CMS capability. This capability has been named Orange WAVE (Warfighter Alliance in a Virtual Environment).

Orange WAVE will become a Joint Exercise & Experimentation Coordination Centre (JE^2C^2) that delivers services (e.g. exercise support) and products (e.g. databases with weapon and sensor interactions, or connections between existing simulation facilities in the Netherlands and abroad). Orange WAVE will be used for mission training and rehearsal, as well as concept development and experimentation for: materiel acquisition, command & control and tactics and doctrine development. Figure 6 gives an overview of the envisioned Orange WAVE capability.

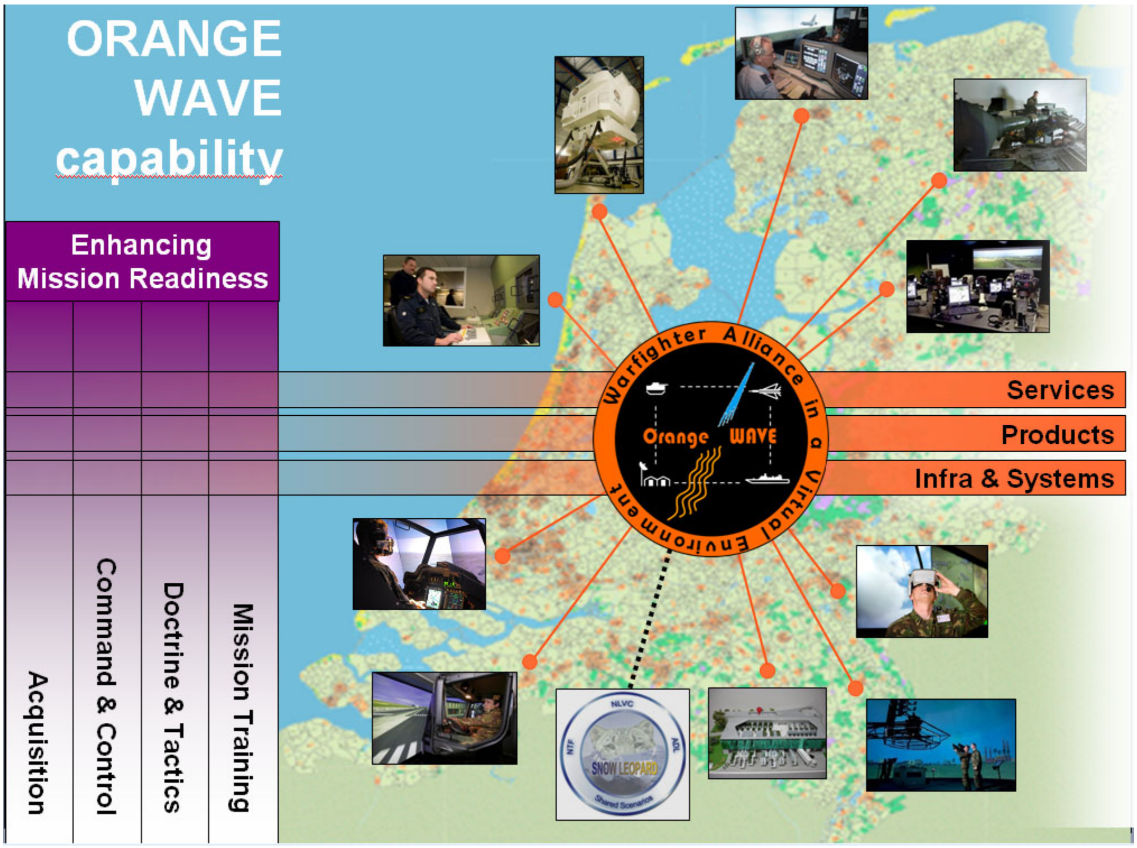

Figure 6. Orange WAVE

To realize its ambition in a feasible and cost-effective manner a phased implementation and iterative development process of the Orange WAVE capability is foreseen between 2010 and 2013. There are many stakeholders and initiatives which will work together in phase 1 and 2 to deliver an Orange WAVE Proof of Concept. The Proof of Concept will deliver an answer to the Royal Netherlands Armed Forces how to set up and organize an Orange WAVE capability in a cost effective manner within the Dutch national context, also leveraging on knowledge, expertise and components present in existing organizations and facilities. The Proof of Concept will also be used to start the Orange WAVE procurement process. In phase 3, Orange WAVE will be developed further in multiple iterations, to become fully operational, in phase 4, as a permanent capability and organization in the Netherlands in 2014.

6 Conclusions

Mission training and rehearsal are vital to successful operations and CMS is an enabler for these purposes. The Royal Netherlands Armed Forces have explored CMS through participation in a number of Live, Virtual and Constructive exercises. The potential of CMS has been recognized and a 4-year national research program into CMS was initiated, which focused on effective realism, interoperable systems across domains and management of the mission information flow.

The CMS program was built around a number of practical use cases and based on a *research by doing* approach. Several technology demonstrations and experiments were held to evaluate solutions for CMS environments from multiple angles, e.g. technically, organizationally and operationally. The program was organized around three main areas: effectiveness in CMS, systems interoperability and management of the mission information flow. In all these areas feasible and novel solutions for CMS have been created and due to the research by doing approach researchers and military operators have gained actual experience with working in a CMS environment.

In this paper we have described the main results of the Dutch national CMS research which will be used for, the phased implementation, of the Dutch national CMS capability, called Orange WAVE. This capability will be used for mission training and rehearsal, as well as concept development and experimentation for: materiel acquisition, command & control and tactics and doctrine development. Orange WAVE will also facilitate future Dutch participation in live, virtual and constructive coalition training events. International cooperation is therefore sought with coalition partners and NATO.

From the progress in our CMS research we have learned that, despite the ongoing technical developments and challenges, the focus, for implementing Orange WAVE successfully, should become more and more on organizational and operational aspects.

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